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FAULT LOCATION AND ISOLATION USING MULTI AGENT SYSTEMS IN 16 BUSES DISTRIBUTION SYSTEM

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ABSTRACT

The Electric power distribution systems are expected to function at all times, even under fault conditions. However, When they operate under fault conditions, the system operator receives information which makes it very difficult to make decisions on whether to restore power distribution system to normal operation. To cope with this uncertainty in decision making, a fault diagnosis method based on Multi Agent System is proposed. The proposed Multi Agent System (MAS) design for fault location and isolation in 16-bus power distribution systems with the presence of Distributed Generation Sources (DGS). In the proposed MAS, agents communicate with their neighbors to locate and isolate the faulty zone. Multi Agent System has a decision making capability. The distributed generation penetration level is considered to be up to 50%. The multi-agent models are simulated in Matlab® Simulink using user defined s-functions and the power system is modeled using the Simulink Simpower toolbox. Using Multi Agent System faulted zone have been identified and isolated successfully. The proposed method has been tested on a model of an existing Mon Power company circuit. Both faulted zone and fault type have been successfully identified.

***KEYWORDS**: Fault Location, Multi Agent System, Distributed Generation, Penetration*

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Original Article

INTRODUCTION

The demand for energy is expected to increase due to a variety of reasons. Power distribution systems are operated by thousands of devices following simple rules with local information. Some of these control devices are already preprogrammed for anticipated situations, but the liberalization of electricity markets or new trends increase interconnectivity between the components and the centralized real-time control becomes more difficult. In the recent years, with the changes in regulatory markets of the generation, transmission and distribution, interest in using new generation technologies like Distributed Generation Sources (DGS) has increased. Distributed generation concept and implementation have been going on for over a decade now with increasing interest due to the numerous advantages it offers such as Voltage support, improved power quality, Loss reduction, Transmission and distribution capacity release, deferments of new or upgraded T&D infrastructure and ability to meet the steep rise in local demand. Using DGS will affect the operation of PDS and new technical issues will be created.

High penetration of DG's changes the traditional passive networks with single direction of power flow to an active network where the power flows in various directions. These changes make the PDS more complicated and more exposed to faults which affect the system's reliability, security, and delivered energy quality [1].

Power utility companies are often faced with the challenge of providing the right level of power quality service to meet the customers need for reliable and high quality power. Reliability of PDS is directly related to the time that utility companies spend on locating and isolating the fault. Fault locating with the minimum time delay can help a fast reconfiguration and restoration for PDS in case of fault occurrence. Therefore fast and accurate fault locating is valuable asset for utility companies to increase their reliability [2].

The prime motive behind this thesis was the significant impact a very accurate fault locator could make if employed in a power transmission and distribution system, in terms of the amount of money and time that can be saved. The main goal of Fault Location is to locate a fault in the power system with the highest practically achievable accuracy. When the physical dimensions and the size of the transmission lines are considered, the accuracy with which the designed fault locator locates faults in the power system becomes very important. However, when extensively studied, it can be noted that a fault locator with satisfactorily high accuracy can be easily achieved by the use of a large amount of data set for training and the learning process [4].

FAULTS

This section present the electricity power system structure, fault theory and the article reviews. It is referred from many researches and source theories which are significant for the researcher for study in fault located identify as followed below:

Electricity Power System

The electricity power system can be classified into generation, transmission, and generation. Generation is used for built the electricity current or voltage from a power plant. Also it is send to a power transmission line after increasing voltage to derived values. The transmission line system carries the electricity quantities that are the power value from generating centres to the load area. Before load center, the voltage is stepped down to normal value for each customer sector such as industrial sector, commercial sector, and other sectors.

There are different voltage values in each area, for instance in India used 380/220 V 50 Hz for distribution system to customer. Thus, the fault may occur in power system from the generating system to customer. The short circuit in power system may effect to a wider power outage. Therefore, we need to diagnose the occurred fault and to identify the location fast. To the time of the short circuit in the electrical system is minimal. The fault types and case of fault in the power system have explained in the next section [5].

Faults Types

A fault is any abnormal electric current. For example, a short circuit is a fault in which current bypasses the normal load. An open-circuit fault occurs if a circuit is interrupted by some failure. In three phase systems, a fault may involve one or more phases and ground, or may occur only between phases. In a "ground fault", The prospective short circuit current of a fault can be calculated for power systems. In power systems, protective devices detect fault conditions and operate circuit breakers and other devices to limit the loss of service due to a failure. In a polyphase system, a fault may affect all phases equally which is a "symmetrical fault". If only some phases are affected, the resulting "asymmetrical fault" becomes more complicated to analyze due to the simplifying assumption of equal current magnitude in all phases being no longer applicable. The analysis of this type of fault is often simplified by using methods such as symmetrical components [5].

Different types of faults can be classified into several types. Some major faults are phase fault such as phase to ground fault, phase to phase fault, phase-phase to ground fault, three phase fault.

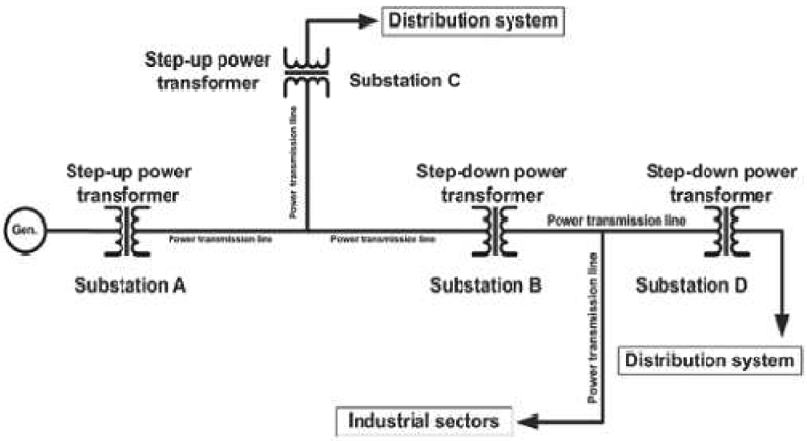

Figure 1: Power System Structure

Symmetrical Faults

These are very severe faults and occur infrequently in the power systems. These are also called as balanced faults and are of two types namely line to line to line to ground (L-L-L-G) and line to line to line (L-L-L).

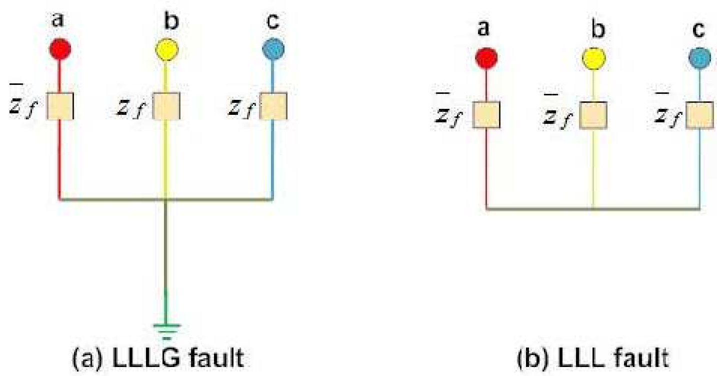

Figure 2: Symmetrical Faults

Only 5% of system faults are symmetrical faults. If these faults occur, system remains balanced but results in severe damage to the electrical power system equipments.

Unsymmetrical Faults

These are very common and less severe than symmetrical faults. There are mainly three types namely line to ground (L-G), line to line (L-L) and double line to ground (LL-G) faults.

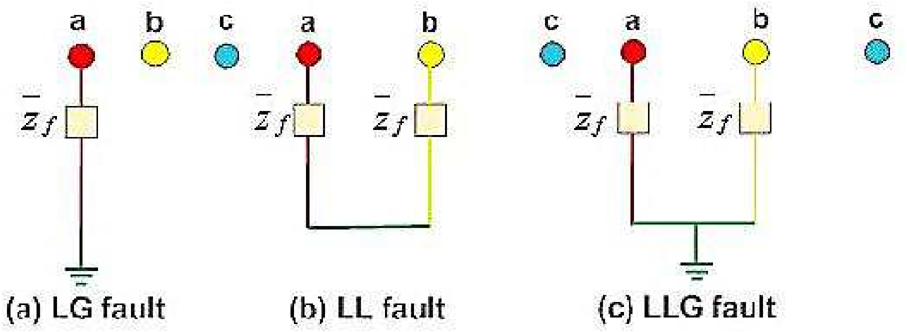

Figure 3: Unsymmetrical Faults

Line to ground fault (L-G) is most common fault and 65-70 percent of faults are of this type. It causes the conductor to make contact with earth or ground. 15 to 20 percent of faults are double line to ground and causes the two conductors to make contact with ground. Line to line faults occur when two conductors make contact with each other mainly while swinging of lines due to winds and 5- 10 percent of the faults are of this type [6].

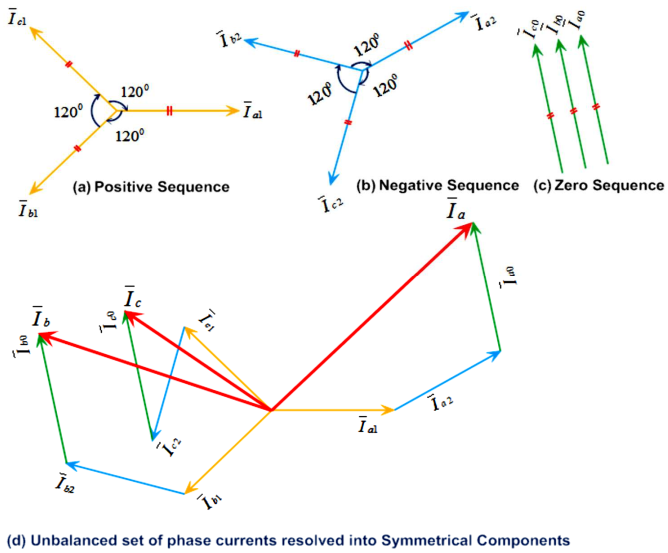

Figure 4: Representation of Symmetrical Components

The graphical representation of the sequence components is shown in figure 4. Let an operator '**a**' be defined such that **a** = $\angle 120^\circ$. Any phasor multiplied by '**a**' undergoes a counter clockwise rotation of 120° without any change in the magnitude. Further,

$\mathbf{a} = 1\angle 120^\circ$

$\mathbf{a}^2 = 1\angle 240^\circ$

$\mathbf{a}^3 = 1\angle 360^\circ$

also $1 + \mathbf{a} + \mathbf{a}^2 = 0$

$\bar{I}_{a1} = I_{a1}\angle\theta_1$

where, $\angle\theta_1$ is the angle of phase 'a' positive sequence current [7].

$\bar{I}_{b1} = \mathbf{a}^2\,\bar{I}_{a1}$

$\overline{I}_{c1} = \mathbf{a}\,\overline{I}_{a1}$

The phase sequence of the positive component set is 'abc'.

Similarly the negative sequence set can be written as:

$\overline{I}_{a2} = I_{a2}\angle\theta_2$

where, $\angle\theta_2$ is the angle of phase 'a' negative sequence current.

$\overline{I}_{b2} = \mathbf{a}\,\overline{I}_{a2}$

$\overline{I}c_2 = a^2\,\overline{I}_{a2}$

The phase sequence of the negative component set is 'acb'.

The zero-sequence component set can be written as:

$\overline{I}_{a0} = \overline{I}_{a0}\angle\theta_0 = \overline{I}_{b0} = \overline{I}_{c0}$

where, $\angle\theta_0$ is the angle of phase 'a' zero sequence current [7].

Causes of Electrical Faults

- Weather conditions
- Equipment failures
- Human errors
- Smoke of fires

Effects of Electrical Faults

- Over current flow
- Danger to operating personnel
- Loss of equipment
- Disturbs interconnected active circuits
- Electrical fires

Fault Limiting Devices

It is possible to minimize causes like human errors, but not environmental changes. Fault clearing is a crucial task in power system network. If we manage to disrupt or break the circuit when fault arises, it reduces the considerable damage to the equipments and also property. Some of these fault limiting devices is:

- Fuse
- Circuit breaker
- Relay
- Lighting power protection devices

FAULT LOCATION

Being able to determine an accurate fault location on a distribution line has become very beneficial, not only in the fact that it helps to reduce the time it takes technician crews to locate the damaged portion of the line, but that in turn, it helps power companies to improve service to customers when a fault does occur. In the past, the fault location techniques implemented were for radial distribution lines. With the penetration of distributed generation on these distribution lines, the line is no longer radial in nature. Therefore, new fault location techniques must be created in order to eliminate the fault location errors inherent with the old fault location techniques when distributed generation is introduced into the system. It has been shown that coordination between protective devices in distribution systems in the presence of significant distributed generation (DG) will be disrupted [8].

The overhead lines in distribution systems are easily exposed to faults, most of which are temporary faults. The performance of fault-location plays an important role in the power systems security and reliability. At the same time, the conventional distribution systems which are radical in nature become multi-source systems and the energy flow is no longer undirectional after distributed generation (DG) connected in. And the traditional fault location methods have been designed assuming the system to be radial and are no longer adaptive to the new distribution systems. So it is necessary to develop a new fault-location algorithm [8].

Fault location problem in distribution systems becomes more complicated with the presence of DGs. The impacts of DGs considerably change depending on their location and size. It is known that an increase in generation capacity, increases the fault current. Thus, introduction of DGs to the radial distribution systems requires further study on existing protective device coordination and protection configuration [9].

Types of Fault Location Methods

Researchers have done considerable work in the area of fault diagnosis particular to radial distribution systems. In recent years, some techniques have been discussed for the location of faults particularly in radial distribution systems. These methods use various algorithmic approaches, where the fault location is iteratively calculated by updating the fault current [8].

Recently, several fault-location methods for transmission, and distribution systems have been proposed. They are categorized in three main categories:

- **Impedance Based Method**

These methods usually calculate the apparent impedance sequences using measurement points data and estimate the possible fault locations based on iterative algorithms [3]. In these approaches, the first, the fault types and faulted phases are identified. Next, the apparent impedance is calculated based on the selected voltage and selected current. If Load currents at different taps are not considered so they are sources of error. this method applied to power line parameter estimation rely on synchronized phasor measurements and require different system operating conditions from which to estimate the parameters.

- **Wavelet Based Method**

In which discrete Fourier transform or wavelet transform are used to analyze the fault waveform. It’s difficult to guarantee the reliability of these methods because of variety of load characteristics and fault cause in PDS. Wavelet is a

mathematical function that satisfies certain mathematical requirements to represent the

Signal in time domain. The fundamental idea behind this is to analyze the signal according to scale, by dilation and translation.

The idea of application of wavelet transform analysis to fault detection in power systems is not new and there are hundreds of publications related to this idea. The wavelet- based techniques are applied in different power system applications such as detecting arcing faults in distribution systems, locating SLG faults in distribution lines, stator ground fault protection schemes with selectivity for generators, locating faults in transmission systems, locating faults in systems with tapped lines and solving inrush current problems [10].

- **Intelligent Method**

Intelligent methods consist of artificial neutral networks (ANN), Expert systems, and multi agent systems (MAS) and etc. ANN based methods need to be trained after any change in system and update the network weights, the other drawback with ANN based methods is that in case of complicated networks they became slow and may fall in local optimum. Expert system methods have a slow response time since they involve knowledge base maintenance and conventional inference mechanism.

These methods can help operators or engineers to do much laborious work. By using these methods, the time factor is substantially reduced and human mistakes are avoided. Therefore, many researchers used AI based methods in distribution system fault locations [10].

DISTRIBUTION GENERATION

Nowadays, an increasing amount of electrical power is generated by decentralized power generators of relatively small scale (i.e. smaller than 50-100 MW).This way of electrical power generation is referred to as "Distributed Generation" (DG) because it is spread out over the system. These small power generators are usually located in the vicinity of the electrical loads, and are mostly connected to distribution networks (i.e. at MV- or LV-networks).

Based on the output power characteristics, DG can be classified as dispatch able or non-dispatch able. The output power of non-dispatch able units, especially the ones driven by renewable energy sources, can show high output power fluctuations.

Distributed generation (or DG) generally refers to small-scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include, but are not limited to synchronous generators, induction generators, reciprocating engines, micro turbines (combustion turbines that run on high-energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, solar photovoltaics, and wind turbines.

Power system stability can be broadly defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to disturbance.

The advantageous side of distributed resources (DR) is the reduction in transmission and distribution (T&D) losses, enhanced service reliability and quality, improved voltage regulation, relieved T&D system congestion [9]. This paper represents the performance of the DG's on the voltage stability of distribution network in terms of voltage sensitivity

factor. So different sorts of DG system have been placed in various position of the distribution network and the bus strength have been determined individually [11].

Applications of Distributed Generating Systems

There are many reasons a customer may choose to install a distributed generator. DG can be used to generate a customer's entire electricity supply; for peak shaving (generating a portion of a customer's electricity onsite to reduce the amount of electricity purchased during peak price periods); for standby or emergency generation (as a backup to Wires Owner's power supply), as a green power source (using renewable technology); or for increased reliability. In some remote locations, DG can be less costly as it eliminates the need for expensive construction of distribution and/or transmission lines.

This system of centralized power plants has many disadvantages. In addition to the transmission distance issues, these systems contribute to greenhouse gas emission, the production of nuclear waste, inefficiencies and power loss over the lengthy transmission lines, environmental distribution where the power lines are constructed, and security related issues.

Many of these issues can be mediated through distributed energies. By locating, the source near or at the end-user location the transmission line issues are rendered obsolete [12].

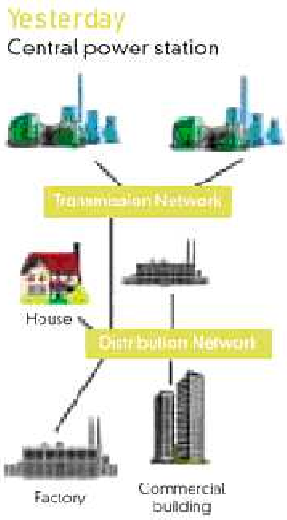

Figure 5: Classic Electricity Paradigm

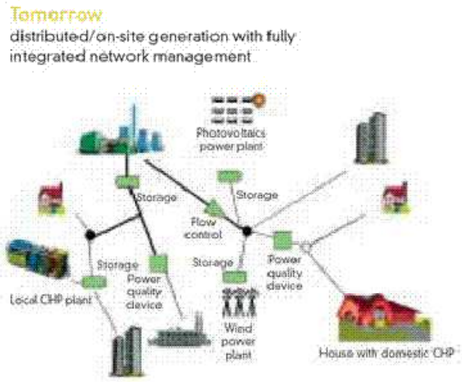

Figure 6: Distributed Generation (DG) Electricity Paradigm

Figure 7: Wind Turbines

Figure 8: Photovoltaic (Solar) Panels

Figure 9: A 300 kW Capstone Microturbine

Benefits of Distributed Generating Systems

Distributed Generation

- Has a lower capital cost because of the small size of the DG (although the investment cost per kVA of a DG can be much higher than that of a large power plant).
- May reduce the need for large infrastructure construction or upgrades because the DG can be constructed at the load location. If the DG provides power for local use, it may reduce pressure on distribution and transmission lines.

- With some technologies, produces zero or near-zero pollutant emissions over its useful life (not taking into consideration pollutant emissions over the entire product lifecycle ie. pollution produced during the manufacturing, or after decommissioning of the DG system).
- With some technologies such as solar or wind, it is a form of renewable energy.
- Can increase power reliability as back-up or stand-by power to customers.
- Offers customers a choice in meeting their energy needs.
- Shorter construction times.
- Reduced financial risk of over- or under-building**.**
- Reduced fuel-forward price risk.
- Reduced trapped equity.
- Potential for lower unit costs for replacement parts when mass produced.
- Displaces that portion of customer load with greatest reactive power requirements [18].

Distributed Generation Penetration

DG Penetration: The ratio of the amount of DG energy injected into the network to the feeder capacity.

$$\text{DG Penetration} = \frac{\text{Capacity factor X DG installed capacity}}{\text{feeder capacity}}$$

The use of distributed generation can replace several needs inside the electric sector. With Distributed Generation requirements of heating, quality supply, improving environment and so on can be covered.

Power distribution systems now controlled by large power generators will be enhanced with more distributed energy resource (DER) architectures in which the demarcations between providers and users of power are less restrictive. The interconnection must allow DG sources to be interconnected with the EPS in a manner that provides value to the end user without compromising reliability or performance [13].

MULTI AGENT SYSTEM

An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors.

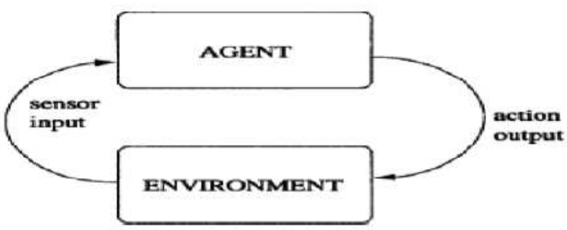

Figure 10: Single Agent System

A multi-agent system is a combination of several agents working in collaboration pursuing assigned tasks to achieve the overall goal of the system. The multi agent system has become an increasingly powerful tool in developing

complex systems that take advantages of agent properties: autonomy, sociality, reactivity and pro-activity.

MAS consists of numerous interacting computing elements, known as agents. Agents are nothing but computer systems with two important capabilities [14].

In a Multi Agent System,

- Each agent has incomplete information
- Control is decentralized
- Data is decentralized
- Computation is asynchronous

Some challenges in developing MAS are task decomposition, defining the agent behavioural rules, agent coordination, setting the environment where agents live [15].

Multi Agent System Architecture

The architecture of an agent is shown in figure 11. The body of each agent is composed of the sensors, communication interfaces, and processing engines. There is a block responsible for communicating with the other agents as shown in figure 12.

In general there are three kinds of control strategies in controlling agents in MAS, centralized, hierarchical and distributed. Figure 11 shows this architectures and agents connections. Centralized approaches are mostly conventional and tend to be inadequate for future power systems [14].

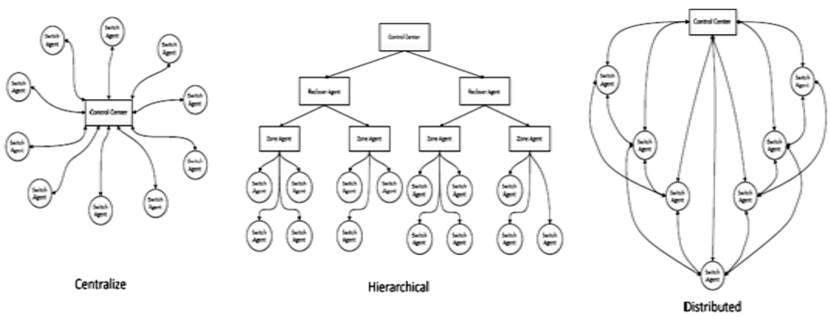

Figure 11: Multi Agent System Architectures

Hierarchical structures are also similar to centralize ones and cannot be considered as a distributed control approach. In the distributed architecture which is used in this paper all agents just communicate with their neighbours and have decision making capability.

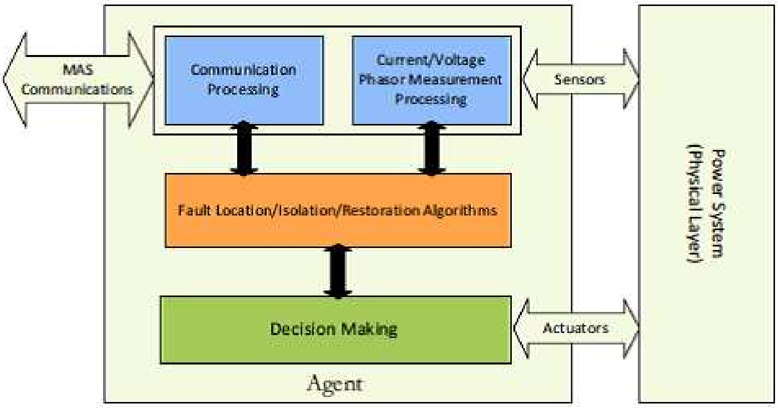

Figure 12: Single Agent Architecture

In this work MAS and power system model are working in real time. It means that MAS and Power system model communicate in real time and the data is accessible to agents without any delay in simulation time. Since most previous works use two different softwares for modeling MAS (JADE, EPOCHS…) and power system (OpenDss, EPDS, …), there are some problems with interfacing the two softwares. In this work both MAS and power distribution system are simulated in MATLAB and there is no need for interfacing the two softwares.

In an engineering context, "inform" and "request" could relate the agent's data transferring where the message contents contain the information (figure 13). After "inform" and sending each data packet, agents wait for acknowledgement. The data should be resend if the acknowledgment is not received. Because agents need the synchronized data of their neighbours for decision making process [16].

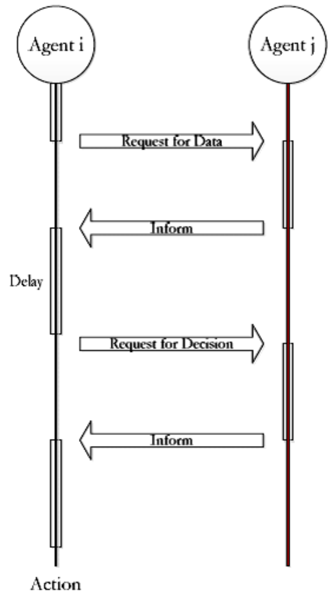

Figure 13: Message Exchange Sketch

SIMULATION MODELS

In this project a standard 16-bus power distribution system will demonstrate improved performance, reliability and security of electric supply through the integration of distributed energy resources and also advanced technologies such

as MAS. A standard 16 bus power distribution system which is shown in figure 14 is modelled with controllable switches using SIMULINK SIMPOWER Tool box.

Simulation results are calculated based on PU values. In this work DGS are modelled as a three phase source in series with RL branch. Lines are modelled based on positive, negative and zero sequence impedance value. Different types of faults such as single line to ground, line to line, double line to ground and three phase faults are modelled with a fault block in SIMPOWER Toolbox and ground resistance is considered to be 0.001Ω. Loads are modelled with active and reactive power. The power system model could simulate in both continuous or phasors or discreet modes.

Main Circuit of Project

In this project, a standard 16-bus power distribution system is divided into four groups (Group 1, Group 2, Group 3, Group 4), are shown in figure 14.

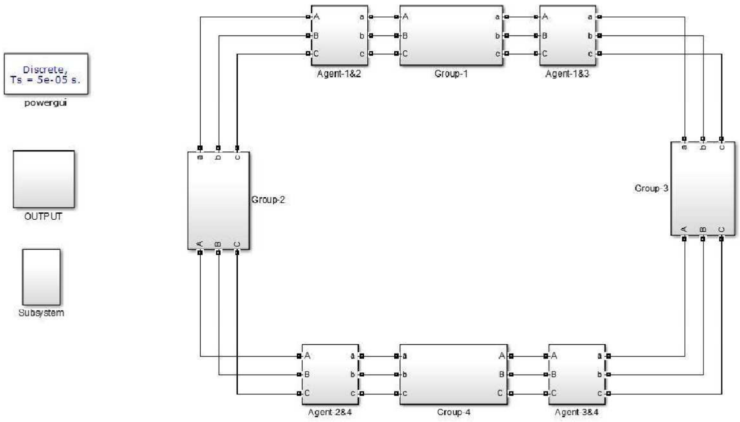

Figure 14: Main circuit for 16 bus PDS

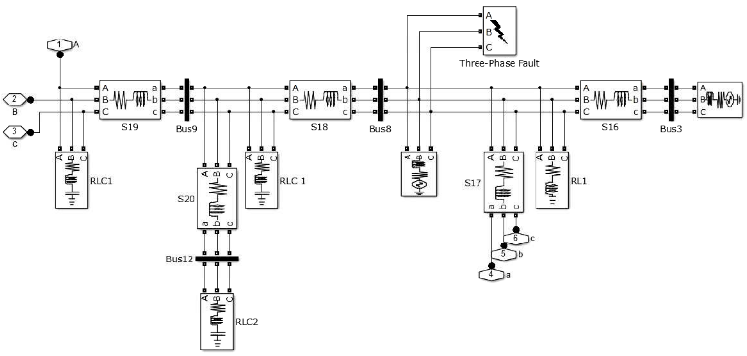

Figure 15: Circuit of Group-1

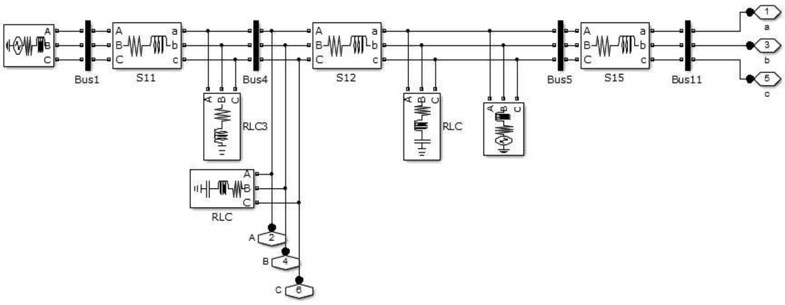

Figure 16: Circuit of Group-2

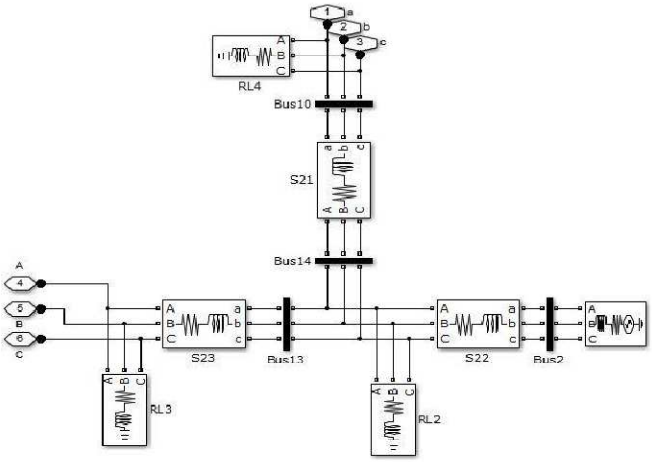

Figure 17: Circuit of Group-3

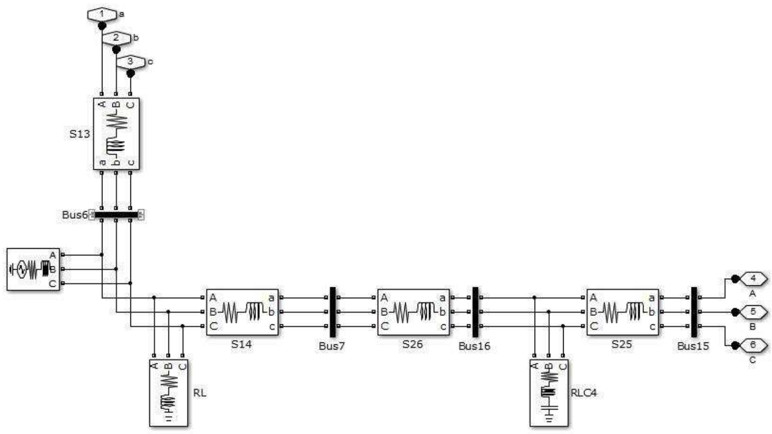

Figure 18: Circuit of Group-4

Agents

The main circuit is divided to Four groups, This groups must be linked by connection circuits put between the groups. The name of the connection circuits is "Agent" are shown the circuit in figure 19. The main work to the Agents is connect the circuits of Groups with each.

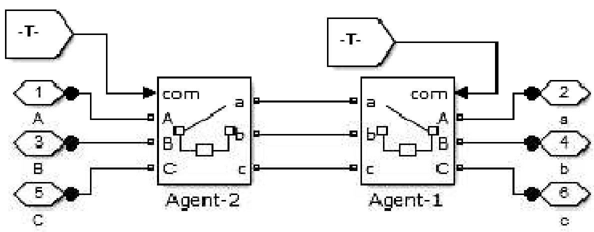

Figure 19: Circuit of Agent

Generating Stations

Electricity generation is the process of generating electric power from other sources of primary energy. This generators are connect with the circuit and operate the main circuit. To operate the circuit,it should has values of the active

power and reactive power of all the generators. Table 1 presents the rating for generators station in all the groups of the main circuit.

Table 1: Generating Station Rating

Generators	Rating
First Generating Group-1	150 KV, 5 MVA
Second Generating Group-1	150 KV, 10 MVA
First Generating Group-2	150 KV, 20 MVA
Second Generating Group-2	150 KV, 10 MVA
Generating Group-3	150 KV, 20 MVA
Generating Group-4	150 KV, 20 MVA

SIMULATION RESULTS

DG Penetration

In order to identify the effect of Distribution Generation Sources on the fault location and isolation application, different penetration level of Distributed Generation sources up to 50 percent are simulated. When there is a fault (three phase fault) in the system recloser will trip according to the time periods. Fault location and isolation system will start its fault location and isolation process following a signal sent to Multi Agent System. Once the fault is detected, MAS will locate isolate the faulted zone and restore power to the unaffected zones.

The operating of each group is give different values for the waveforms of penetration, Table 2 show the results of penetration levels for more scenarios. The operating of groups is separate for each one, this for notice the fault and know the exact values for the penetration and other values.

Table 2: Penetration Levels

	Scenario	Zone 1 Change Percentage	Zone 2 Change Percentage	Zone 3 Change Percentage	Zone 4 Change Percentage
1	Single line to ground fault at Zone 1	85	-29	-29	-30
2	Single line to ground fault at Zone 2	-27	30	-28	-27
3	Single line to ground fault at Zone 3	-25	-26	10	-25
4	Single line to ground fault at Zone 4	-30	-30	-30	850

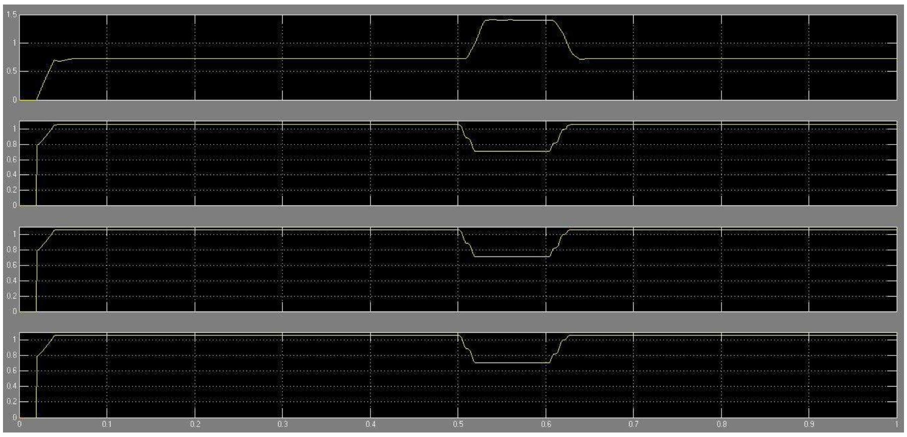

Figure 20: MAS with Penetration of Group-1

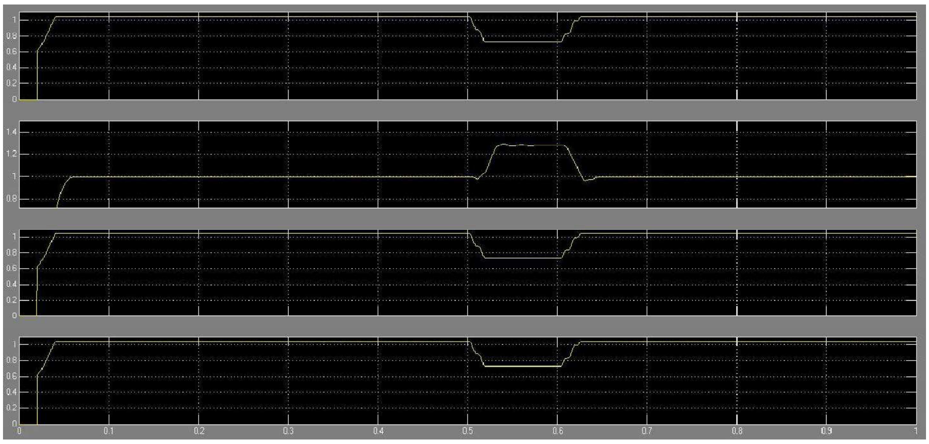

Figure 21: MAS with Penetration of Group-2

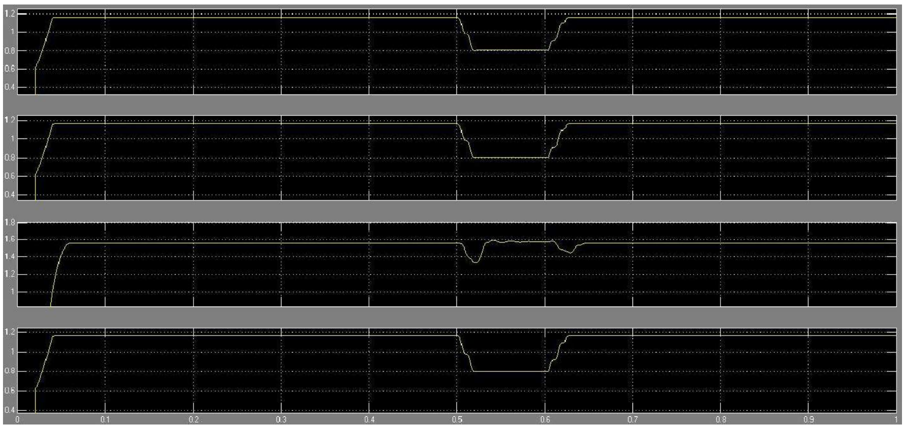

Figure 22: MAS with Penetration of Group-3

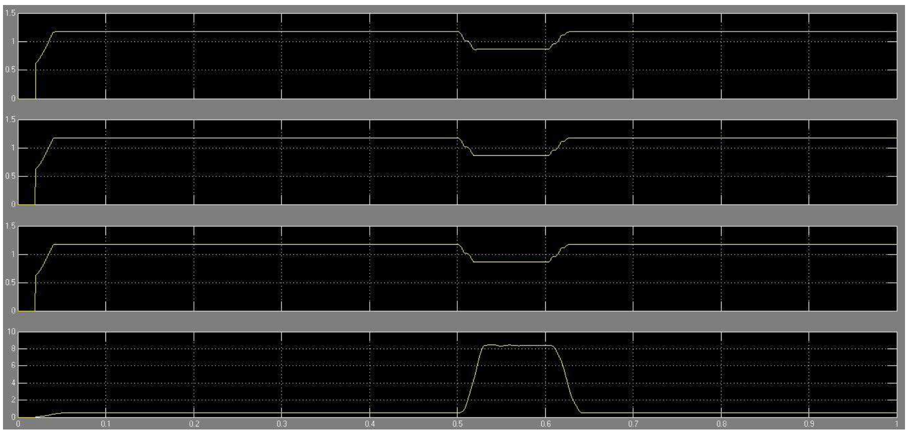

Figure 23: MAS with Penetration of Group-4

CONCLUSIONS

This project presents a decentralized Multi Agent System (MAS) which works in real time with a power distribution system for fault diagnosis applications. The agents use local voltage and current data information for fault location and isolation process.

In this work both power distribution system and multi agent system are simulated in MATLAB\SIMULINK, and therefore, there is no need for an interface between the two models.

The proposed method is tested with Distributed Generation penetration for all the groups (or zones) when the fault is occurs, and applicated the (MAS) with penetration for each group on other groups and notice the change percentage of each group (zone).

Faulted zone can be identified and isolated successfully. This advantages presents a easier and absolute accurate simulation model for identifying application of Multi Agent System (MAS) in power distribution system.

FUTURE WORK

In future works this simulation model will be used to support our research in using multi-agents for restoration and reconfiguration processes after fault location and isolation.

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